IOT-Based Crop Monitoring System

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Abstract— This paper proposes the development of a smart monitoring crop production system based on the Internet of Things (IoT) for Controlled Environment Agriculture (CEA) to address the limitations in domestic-level and underdeveloped countries' crop production. The system aims to optimize crop growth by monitoring and controlling key environmental factors, including soil moisturization, temperature, light intensity, humidity, and soil nutrients. The project is divided into five main steps: the monitoring system, controlling system, design and analysis, actuators integration, and prototype modelling.

The monitoring system utilizes sensors, such as DHT11 and NPK, to collect data, which is processed by a microcontroller (ESP 32) and displayed using IoT technology. The controlling system, integrated with the monitoring system through ESP 32, regulates the closed environment based on the collected data. To maintain optimal temperature and humidity levels, the system employs fans and humidifiers. The design and analysis phase involve creating a model using FUSION 360 and performing thermal analysis to determine cooling and heating load requirements. Actuators, such as soil moisture sensors, are integrated into the system to monitor and maintain appropriate soil moisture levels. The prototype model is constructed using wood and polythene, with all systems installed within it.

The main objectives of this project are to establish an optimum environment for crop production using mechanical applications, understand refrigeration system applications through load calculations, and develop a feedback mechanism for the control system. By implementing a smart monitoring system, this project aims to bridge the gap between advanced agricultural technologies and domestic-level crop production, ensuring cost-effectiveness, reduced power consumption, and enhanced crop production. This will make agriculture more efficient, sustainable, and accessible even at the domestic level.

Keywords*: CEA (Controlled Environment Agriculture), IOT (Internet of Things), Smart Farming, Refrigeration System, Feedback Mechanism.*

I. INTRODUCTION

The field of agriculture has witnessed significant advancements in automation, robotics, artificial intelligence, and smart farming, particularly on an industrial scale and in developed countries. However, crop production at the domestic level and in underdeveloped countries still faces limitations and falls short of desired outcomes, impacting their economic situation. To address this disparity, we propose the development of a smart monitoring crop production system based on the Internet of Things (IoT) within the domain of Controlled Environment Agriculture (CEA).

Controlled Environment Agriculture (CEA) is an emerging field in modern studies that aims to optimize crop growth by monitoring and controlling key environmental factors, including water level, temperature, humidity, and soil nutrients. This project focuses on establishing a closed system, similar to a greenhouse, which enables precise control of these factors to create an optimum growth environment for crops.

The project consists of five main steps: the monitoring system, controlling system, design and analysis, actuators integration, and prototype modelling. The monitoring system employs sensors to collect data, such as the DHT11 sensor for temperature and humidity monitoring, and the NPK sensor to measure soil nutrients like nitrogen, phosphorus, and potassium. This data is processed by the ESP 32 microcontroller and displayed using IoT technology.

The controlling system is interconnected with the monitoring system via the ESP 32 microcontroller and regulates the closed environment by dynamically adjusting temperature, humidity, and other factors. Components such as fans and humidifiers are utilized to maintain optimal conditions based on real-time data and programmed algorithms.

Design and analysis play a crucial role in this project, involving the creation of a structural model using Fusion 360 software and performing thermal analysis using ANSYS to determine the cooling and heating load requirements of the system.

Actuators, including soil moisture sensors, are integrated into the system to monitor and regulate soil moisture levels. When deviations from the desired range occur, the controller takes corrective actions to restore optimal conditions.

The prototype model is constructed using wood and Acrylic sheets, accommodating all integrated systems and providing a tangible representation of the proposed smart monitoring crop production system.

The primary objectives of this project are to establish an optimum environment for crop production, comprehend the application of refrigeration systems through load calculations, and develop a feedback mechanism for the control system. By implementing a smart monitoring system, this project aims to bridge the gap between advanced agricultural technologies and domestic-level crop production, ultimately improving efficiency, sustainability, and

accessibility of agriculture, particularly in underdeveloped countries.

The research gap addressed by this project pertains to the underdeveloped countries where advanced agricultural technologies are lacking, resulting in limited crop production and adverse economic implications. By simplifying system design and reducing power consumption, this project seeks to make Controlled Environment Agriculture (CEA) cost-effective and applicable in various agricultural settings, thereby addressing the challenges faced by underdeveloped countries.

II. Literature Review

Technology has made remarkable advancements in the field of agriculture, particularly on industrial scale, in past decade. Automation has been implemented to enhance agricultural processes, with robots and drones equipped with sensors playing a crucial role in weed detection and removal. Scientists emphasizes the significance of using sensors on robots and drones to detect weeds, which not only affect crop growth but also lead to resource wastage and disease. By employing a feedback mechanism, these autonomous systems can take specific actions to eliminate weeds, optimizing resource utilization and crop health.[10]

Smart farming has gained traction in recent years, enabling monitoring and control of environmental parameters crucial to crop growth, such as water, nutrients, humidity, light, and temperature. Oluyemi highlights the advantages of smart farming in providing real-time monitoring, identifying challenges, and identifying open research issues in farming practices. This approach assists addressing agricultural challenges and improving farming efficiency.[8]

Researchers have conducted extensive work in the field of agriculture and technology to enhance crop production and address global food security needs. Bibliometric studies have been utilized to identify key areas of interest and explore academic work published in countries that present research opportunities. Nahina Islam (2021) highlights the significance of bibliometric methods and knowledge graph techniques in understanding research trends in AI and sustainable agriculture, helping future researchers focus their efforts accordingly.[12]

In the realm of global agricultural remote sensing, the bibliometric method and knowledge graph method, assisted by artificial intelligence, have been used to examine research competitiveness, cooperation, authors, and topics. Bing Bai (2022) showcases the efficacy of these methods in providing an overview of research in agricultural remote sensing, enabling a deeper understanding of the field's progress and identifying collaborative opportunities.[11]

These studies underscore the remarkable advancements in technology, including automation, artificial intelligence, and smart farming, within the agricultural domain. The integration of sensors, AI systems, and monitoring technologies has the potential to revolutionize crop production, enhance resource efficiency, and address global food security challenges. However, further research and development are necessary to optimize these technologies and make them more accessible and cost-effective in various agricultural settings.

III. Methodology

A. Microcontroller Selection and Software Setup:

The selection of an appropriate microcontroller was a critical aspect of designing the monitoring and controlling system. Several factors were considered, including processing power, compatibility with sensors and actuators, communication capabilities, and ease of programming. The chosen microcontroller must meet the specific requirements of the system and facilitate its precise integration with the selected sensors and actuators. Through careful evaluation and comparison of available options, we identified the most suitable microcontroller (ESP 32) for their application.

To facilitate real-time monitoring and visualization, a connection was established between the microcontroller and the Blynk software platform. We developed code to transmit sensor data to the Blynk application, allowing users to monitor and visualize the environmental parameters in real-time. This interface with Blynk software provided a user-friendly platform for data visualization, enabling users to analyze and interpret the monitored parameters conveniently.

To ensure precise data transmission between the microcontroller and devices, the required drivers were installed. This installation process facilitated proper synchronization and interaction between the microcontroller and connected devices, ensuring accurate data collection and transmission.

B. Humidity and Temperature Monitoring:

To accurately monitor humidity and temperature, we developed code to read and process data from the respective sensors. The code algorithms were designed to account for sensor-specific characteristics and calibration factors, enabling precise and reliable monitoring of humidity and temperature. The code also incorporated data acquisition techniques to ensure real-time data updates and accurate measurements.

To enable effective data collection from the required sensors, the necessary libraries were inserted. This step ensured compatible integration with the selected sensors. By incorporating the appropriate libraries, we could effectively interface with the sensors to retrieve data, and perform specified tasks. This integration of libraries played a crucial role in the successful implementation of the smart monitoring system.

C. NPK and Soil Moisture Monitoring

In order to monitor soil nutrient levels and moisture content, we developed code to collect data from the NPK sensor and soil moisture sensor. The coding process involved the implementation of algorithms to interpret sensor readings accurately. These algorithms considered sensor characteristics, calibration factors, and specific soil properties to provide precise measurements of nutrient levels and moisture content. The code allowed for real-time monitoring of these crucial parameters, enabling effective management of crop production.

D. CAD Design and System Analysis:

A CEA (Controlled Environment Agriculture) CAD model incorporating a sliding mechanism was developed using Autodesk Fusion 360. The use of Fusion 360 allowed for precise design modeling and visualization of the prototype.

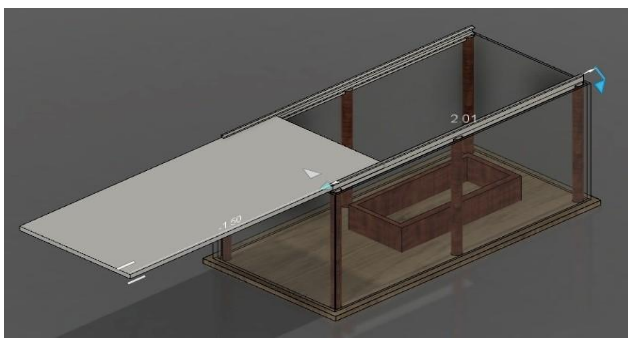

Figure 1. CEA CAD Model

After creating the CAD model, a thermal analysis was conducted using ANSYS Workbench to evaluate the temperature distribution and heat flux through materials such as acrylic and wood. The purpose of this analysis was to assess the thermal behavior of these materials when subjected to the operating conditions of the crop production system. By simulating the thermal analysis, including heat sources and ambient conditions, we were able to obtain valuable insights into the temperature distribution and heat transfer characteristics of the materials.

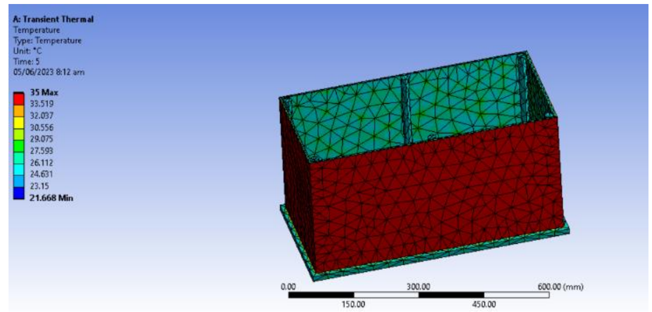

Figure 2. Thermal Analysis : Temperature Distribution

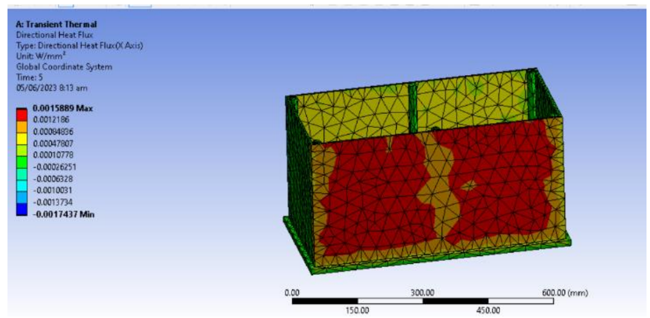

Figure 3. Thermal Analysis :Heat Flux

E. Calculation for Cooling load and Refrigeration capacity:

Specifications

- CEA system dimensions is 1x1 ft2 / 0.3048x0.3048 m2 for 2 sides and 1x2 ft2 / 0.3048x0.6096 m2 for 2 sides
- Total number of systems are 1
- Ceiling height is taken to be 1ft / 0.3048m.
- Nature of working is full time

Solar radiation through Sheet:

Radiant energy through sun passes through the transparent material such as Acrylic and became a heat gain to a room. The solar cooling load can be found by using the following formula:

$$QG = SHGF \times A_p \times SC \times CLF$$

SHGF = Maximum solar heat gain factor in BTU/hr- $ft^{2.}$

AG = Area of the acrylic sheet

SC = Shading coefficient

CLF = Cooling load factor for a acrylic.

For side 1

Heat gain for window is

Q = (0.6096)(0.87)(785)(0.2) = 83.26 W

For side 2

Heat gain for window is

Q = (0.6096)(0.87)(785)(0.22) = 83.36 W

For side 3

Heat gain for window is

Q = (2.25)(0.87)(90)(0.2) = 6.64 W

For side 4

Heat gain for window is

Q = (1.875)(0.87)(90)(0.3) = 4.36 W

Total Q = 4.36+6.64+83.36+83.26
Total Q = 177.62 W

Conduction through Acrylic sheet

$$Q = (UA(T\_O - T\_i))$$

Ambient temperatrure = 50℃
Relative Humidity = 70%
Insulation = 0.25 mm
U= 4.5 W/m^2.k

$$Q = ((4.5)(1.25)(35 - 27)(24))$$
$$Q = 1728 \text{ W}$$

$$Q_{net} = 1728 + 177.62$$
$$Q_{net} = 1905.62\text{W}$$

Using Safety factor = 1.3

$$Q_{net} = (1905.62)(1.3)$$
$$Q_{net} = 2477.31 \text{ W}$$

IV. Results And Discussion

In this section, we present the results obtained from the IoT-based smart crop monitoring system and discuss their implications. The data collected and analyzed from the various sensors and components of the system provide valuable insights into the environmental conditions and nutrient levels affecting crop growth.

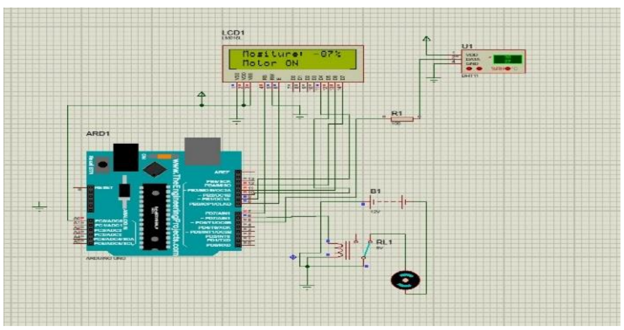

Figure 4. Simulation Moisture Sensor

The presented Fig.4 and Fig.5 demonstrate the relationship between moisture levels and the operation of motors within the smart monitoring crop production system. Based on the analysis, it is observed that when the moisture level reaches 100%, the motors are turned off, indicating an automated control mechanism to prevent over-irrigation or excessive moisture in the growing environment. Conversely, when the moisture level falls below 100%, the motors are activated to ensure adequate irrigation and maintain optimal moisture conditions for crop growth. This functionality showcases the system's capability to regulate irrigation activities based on real-time moisture data, thereby promoting efficient water usage and supporting optimal crop health and productivity.

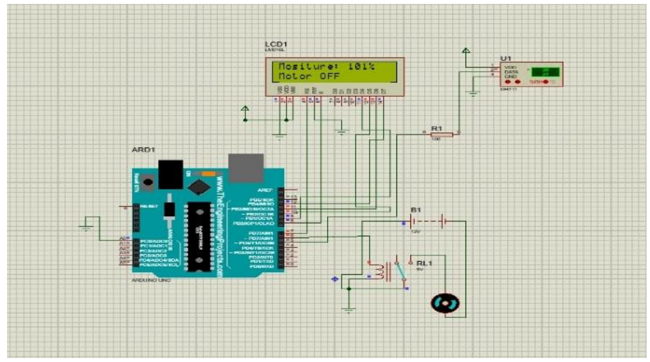

Figure 5. Simulation Moisture Sensor

The obtained results indicate the effectiveness of the IoT-based smart crop monitoring system in providing real-time information about the crop's growing conditions. The temperature and humidity measurements provide insights into the environmental factors to inhance crop growth at optimal conditions. The soil nutrient monitoring helps in understanding the nutrient availability in the soil and optimizing fertilization strategies.

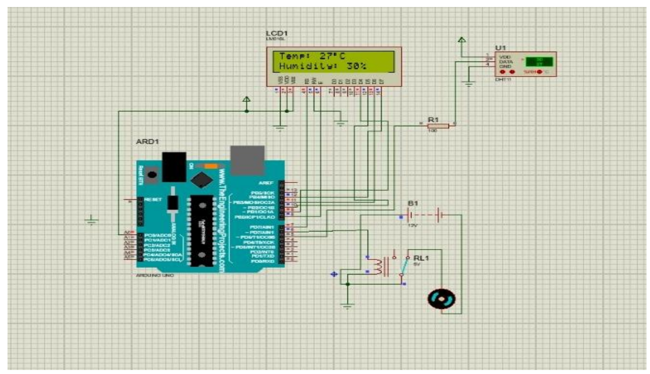

Figure 6. Simulation Temperature & Humidity Sensor

The provided Fig.6 showcase temperature control, temperature monitoring, humidity control, and humidity monitoring within the smart monitoring crop production system. These visual representations demonstrate the system's capability to regulate and maintain optimal temperature and humidity levels, ensuring an optimum growing environment for crops. The temperature control function adjusts cooling mechanisms to maintain the desired temperature, while the temperature monitoring feature provides real-time data for continuous monitoring. Similarly, the humidity control and monitoring functionalities work together to regulate and monitor humidity levels. These visuals highlight the system's effectiveness in accurately controlling and monitoring temperature and humidity, contributing to improved crop production efficiency and yield.

Furthermore, the integration of IoT technology and the feedback mechanism in the controlling system allows for automated regulation of the environment based on the monitored data. This not only minimizes human intervention but also ensures a more precise and efficient control of the crop growing conditions.

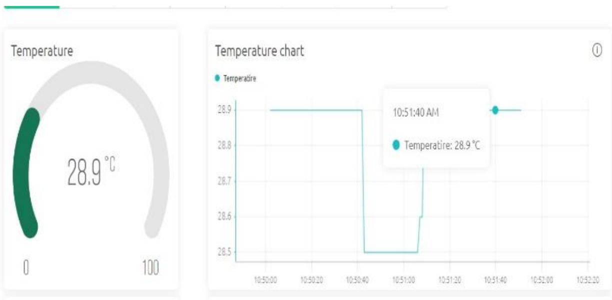

Figure 7. Temperature & Humidity Monitoring

Figure 8. Temperature & Humidity Monitoring

The presented graphs depict the dynamic behavior of temperature and humidity over time. These graphical representations provide valuable insights into the trends and patterns of temperature and humidity fluctuations within the monitored environment.

V. Conclusions

In this research, an IoT-based smart crop monitoring system was developed for Control Environment Agriculture. The system successfully monitored and controlled key environmental parameters such as temperature, humidity, soil nutrients, and soil moisture.

The results obtained from the system's monitoring capabilities demonstrated its effectiveness in providing valuable insights for crop management. The real-time data collected and analyzed allowed researchers, agronomists, and policymakers to the discovery of patterns, trends, and correlations that can inform the development of new farming techniques, improved crop varieties, and sustainable agricultural practices. This iterative process of data analysis and experimentation promotes innovation and drives the agricultural industry towards greater efficiency, sustainability, and resilience.

Furthermore, the integration of feedback mechanisms into the controlling system enabled automated regulation of the environment based on the monitored data. This automation has revolutionized industries by increasing efficiency, reducing human error, and streamlining processes. It has led to improved productivity, cost savings, and enhanced operational performance across various sectors.

The implementation of the IoT-based smart crop monitoring system offers several advantages for farmers, this technology provides real-time access to vital information about their crops, including temperature, humidity, soil moisture, and nutrient levels. By leveraging this data, farmers can make informed decisions regarding irrigation, fertilization, pest control, and overall crop management.

The scalability and adaptability of the system make it suitable for implementation in CEA systems can be deployed in smart greenhouses, Domestic level small-scale or home-based agriculture, livestock monitoring setups, and various agricultural farms to optimize crop production, enhance livestock management, and improve overall agricultural practices.

Overall, the IoT-based smart crop monitoring system presented in this research has the potential to revolutionize designed CEA Systems to overcome the limitations of traditional agricultural methods, which are heavily dependent on external weather conditions and often subject to environmental fluctuations and constraints. By creating a controlled environment, CEA systems enable year-round cultivation of crops, independent of geographical location and climatic conditions.

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